C#/.Net Project Cluster

C# vs. Java

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C#/.Net project cluster
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- About the course materials and the teacher.
- What is C# and when will C# 2.0 be available?
- Comparison of C# and Java (Monday).
- Plain ODBC database access from C# (Monday).
- Generic types and methods (Tuesday).
- C# attributes and reflection (Tuesday).
- Iterators: the `yield` statement (Wednesday).
- Anonymous methods: `delegate` expressions (Wednesday).
- SQL-style nullable value types: `int?`, `bool?`, and so on (Wednesday).
- Graphical user interfaces with Windows Forms (Wednesday).

The teacher

MSc and PhD in computer science from DIKU, University of Copenhagen.

At DTU 1992–1994; at AT&T Bell Labs USA 1994–1995; at KVL since 1995 and at ITU since 1999.

Co-developer of the C5 generic collection library for C#/CLI, see `http://www.itu.dk/research/c5`

Books:

- Jones, Gomard, Sestoft: *Partial Evaluation and Automatic Program Generation* (Prentice-Hall 1993)
- Sestoft: *Java Precisely* (MIT Press 2002, second edition 2005)
- Sestoft and Hansen: *C# Precisely* (MIT Press 2004).

Member of the Ecma standardization committees for C# and CLI (Common Language Infrastructure, part of .Net).

The course materials

- *C# Precisely*, available from the ITU bookstore.
  Example files at `http://www.dina.kvl.dk/˜sestoft/csharpprecisely/`
- Online documentation of .Net 2.0 class library at
  `http://msdn2.microsoft.com/library/default.aspx`
- C# 2.0 standard at `http://www.dina.kvl.dk/˜sestoft/ecma/`

Software

- Microsoft Visual Studio 2005 (includes C# compiler and .NET runtime) is installed on classroom computers.
- The free Microsoft Visual C# 2005 Express can be downloaded from
  `http://msdn.microsoft.com/vstudio/express/`
- You can use also Mono from `http://www.mono-project.com/`, especially if you use Linux.

What is C#?

A class-based single-inheritance object-oriented programming language with a managed execution environment.

Just like Java, but with many improvements — and also with additional complexity.

Designed to be the main programming language for Microsoft .Net, alias CLI = Common Language Infrastructure.

CLI is the infrastructure of VB.Net, JScript.Net and Managed C++; and of future Microsoft products.

C# has considerable syntactic similarity to Java:

```
using System;
class Hello {
  static void Main(String[] args) {
    Console.WriteLine("Hello, " + args[0]);
  }
}
```

C# 2.0 was released as part of Microsoft Visual Studio 2005 in November 2005, for Microsoft Windows only.

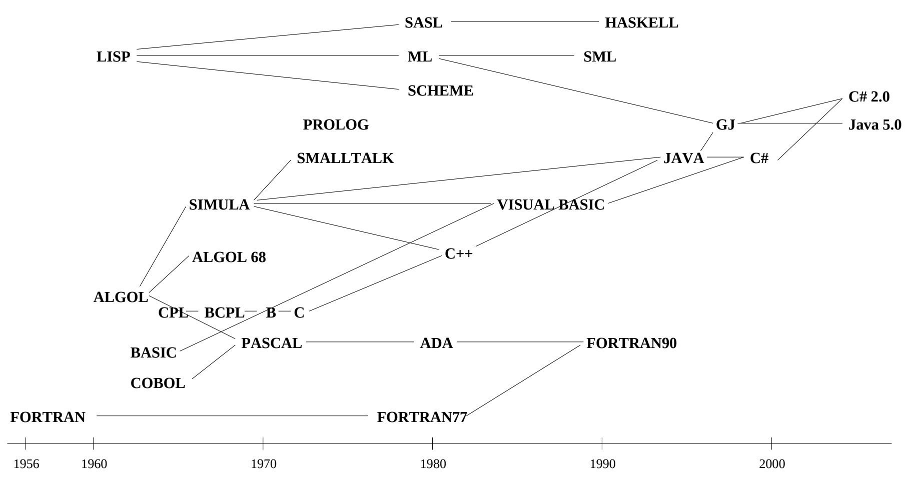
Mono version 1.1.15 (April 20056) gives a good beta-quality preview of C# 2.0 for Linux and other platforms.

Comparison of Java and C#

Most of C# is immediately recognizable to a Java programmer. Some differences:

- Virtual *and* non-virtual instance methods.
- Implicit boxing and unboxing of primitive types (also in Java 5.0).
- Properties — field-style method calls.
- Indexers — array-style method calls.
- Enumerators (iterators) and the `foreach` statement (also in Java 5.0).
- Operator overloading — as in C++.
- Delegates — method closures.
- Value types and structs — allocated on stack, inlined in objects and arrays, copied on assignment and so on.
- Enum types — as in C/C++ (also in Java 5.0).
- Reference parameters (`ref` and `out`) — much like Pascal, Ada, C++.
- Variable-arity methods (`params` modifier; also in Java 5.0).
- No inner classes, no `throws` clause on methods.
- Unsafe code with pointer arithmetic and so on — discouraged, but possible.

Genealogy of some programming languages



Comparison of Java, C#, C++ and C

Feature	Java	C#	C++	C
Automatic memory management	+	+	–	–
Exceptions	+	+	+	–
Array bounds checks	+	+	–	–
Classes	+	+	+	–
Structs (value types)	–	+	+	+
Interfaces	+	+	–	–
Inheritance	+	+	+	–
Multiple inheritance	–	–	+	–
Virtual methods	+	+	+	–
Non-virtual methods	–	+	+	–
Method overloading	+	+	+	–
Nested classes	+	+	+	–
Inner classes	+	–	–	–
Call-by-value parameters	+	+	+	+
Reference parameters	–	+	+	–
Safe variable-arity methods	5.0	+	–	–
Properties	–	+	–	–
Indexers	–	+	+	–
Looping over iterators	5.0	+	+	–
Defining iterators (`yield`)	–	2.0	–	–
User-defined operators	–	+	+	–
User-defined conversions	–	+	–?	–
Enum types	5.0	+	+	+
Autoboxing simple values	5.0	+	–	–
Nullable value types	–	2.0	–	–
Rectangular arrays	–	+	+	+
Arrays of arrays	+	+	(–)	(–)
Compile-time conditional code	–	+	+	+
Generic types and methods	5.0	2.0	(+)	–
Runtime type parameter info	–	2.0	–	–
Wildcard types (existentials)	5.0	–	–	–
Generic collection library	5.0	(–)	(+)	–
Anonymous methods	(–)	2.0	–	–
Metadata (attributes/annotations)	5.0	+	–	–

Different conventions

	Java	C#
Classes	`MyClass`	`MyClass`
Interfaces	`MyInterface`	`IMyInterface`
Methods	`myMethod`	`MyMethod`
Fields	`myField`	`myField`
Local variables	`myVariable`	`myVariable`
Packages/Namespaces	`java.lang.reflect`	`System.Reflection`

For detailed coding and design guidelines, see K. Cwalina and B. Abrams: *Framework Design Guidelines: Conventions, Idioms, and Patterns for Reusable .NET Libraries*, Addison-Wesley 2005.

Value types and reference types (C# Precisely section 5.1, examples 84 and 86)

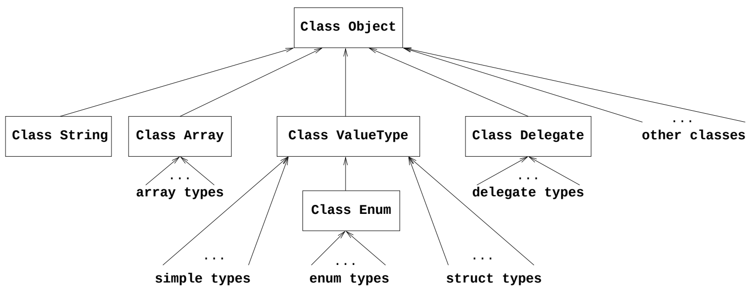
A C# type is either a *reference type* (class, interface, array type) or a *value type* (`int`, `double`, ...).

- A value (object) of reference type is always stored in the managed (garbage-collected) heap.

  Assignment to a variable of reference type copies only the reference.
- A value of value type is stored in a local variable or parameter, or inline in an array or object or struct value.

  Assignment to a variable of value type copies the entire value.

Just as in Java. But in C#, there are also user defined value types, called struct types (as in C/C++):



A struct type is a value type (C# Precisely section 11 and 14)

Objects are always allocated in the heap. Allocating many small objects is expensive.

In C#, use struct types to represent pairs, fractions, complex numbers and other small values.

A struct type is similar to a class; but has no base type and no virtual methods; may implement interfaces.

Example: Representing fractions `n/d`:

```
struct Frac : IComparable {
  public readonly long n, d;       // NB: Meaningful only if d!=0
  public Frac(long n, long d) {
    long f = Gcd(n, d); this.n = n/f; this.d = d/f;
  }
  ...
  private static long Gcd(long m, long n) { ... }
}
```

Struct types are used just like classes:

```
Frac r1 = new Frac(6, 2), r2 = new Frac(5, 2);
Console.WriteLine("r1={0} and r2={1}", r1, r2);
```

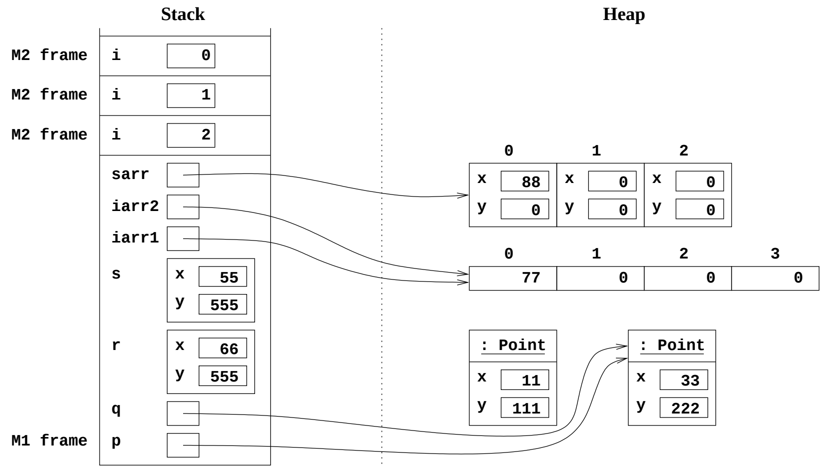
A `Frac` value is stored directly in a variable, such as `r1`, not in the heap.

Assigning a struct value copies it, so struct values should usually be immutable: fields should be `readonly`.

The machine model (C# Precisely example 64)

Class instances (objects) are individuals in the heap.

Struct instances are in the stack, or inline in other structs, objects or arrays.

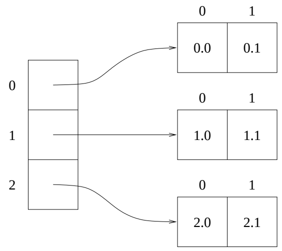


Rectangular multi-dimensional arrays (C# Precisely section 9.2.1)

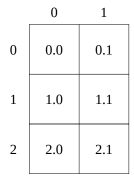
In Java, a ‘multi-dimensional’ array is a one-dimensional array of arrays.

C# in addition has C-style rectangular multi-dimensional arrays.

This improves memory locality (speed) and reduces memory consumption (space).



Array of arrays (`double[][]`)



Rectangular array (`double[,]`)

Example: Two equivalent ways to allocate and initialize a rectangular two-dimensional array:

```
double[,] r1 = { { 0.0, 0.1 }, { 1.0, 1.1 }, { 2.0, 2.1 } };
double[,] r2 = new double[3,2];
for (int i=0; i<3; i++)
  for (int j=0; j<2; j++)
    r2[i,j] = i + 0.1 * j;
```


Rectangular array of arrays

Example: Storing the USD/EUR exchange rate for every day in the years 2000–2009.

A 2D array of 1D arrays of `double`: 10 years times 12 months times a varying number of days.

```
double[,][] rate = new double[10,12][];
rate[0, 0] = new double[31];        // Jan 2000 has 31 days
rate[0, 1] = new double[29];        // Feb 2000 has 29 days
rate[0, 2] = new double[31];        // Mar 2000 has 31 days
...
rate[0, 1][27] = 0.9748;            // 28 Feb 2000
rate[0, 1][28] = 0.9723;            // 29 Feb 2000
rate[0, 2][ 0] = 0.9651;            //  1 Mar 2000
```


Non-virtual methods (C# Precisely section 10.7 and 10.8)

In Java, a method that is not static or private is automatically virtual.

C# has four kinds of (non-abstract) method declarations; the three first ones are known from C++:

- Static: `static void M()`

  A call `C.M()` is evaluated by finding the method `M` in class `C` or a superclass of `C`.
- Non-virtual and non-static: `void M()`

  Assume that `T` is the *compile-time type* of `o`.

  Then a call `o.M()` is evaluated by finding the method `M` in class `T` or a superclass of `T`.
- Virtual and non-static: `virtual void M()`

  Assume that `R` is the *runtime class* of the object that `o` evaluates to.

  Then a call `o.M()` is evaluated by finding the method `M` in class `R` or a superclass of `R`.
- Explicit interface member implementation: `void I.M()` — see C# Precisely section 15.3.

  Implements `M` from interface `I`, which must be a base interface of the enclosing class or struct type.

  Assume that `R` is the *runtime class* of the object `o` evaluates to, and that `I` is the *compile-time type* of `o`.

  Then a call `o.M()` is evaluated by calling method `I.M` in class `R` or a superclass of `R`.

  Useful when a class implements several interfaces that describe distinct methods with the same name.

C#: Virtual and non-virtual method example

```
class A {
  public virtual void m1() { Console.WriteLine("A.m1()"); }
  public void m2() { Console.WriteLine("A.m2()"); }
}

class B : A {
  public override void m1() { Console.WriteLine("B.m1()"); }
  public new void m2() { Console.WriteLine("B.m2()"); }
}

class Override {
  static void Main(string[] args) {
    B b = new B();
    A a = b;
    a.m1();             // B.m1()
    b.m1();             // B.m1()
    a.m2();             // A.m2()
    b.m2();             // B.m2()
  }
}
```

A virtual method call is governed by the *runtime class* of `a`; a non-virtual method call by the *compile-time type*.

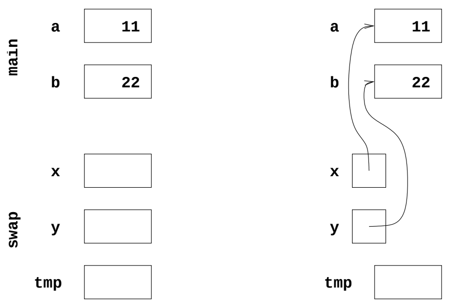
The `override` and `new` keywords are needed (their purpose is to prevent accidental overriding or hiding).

Reference parameters (C# Precisely sections 10.7, 12.15.2; examples 84, 86)

Call-by-value is similar to assignment: copies the argument value to the method parameter.

Call-by-reference makes the method parameter refer directly to the argument.
The argument must be a variable or field or array element (that is, must have an lvalue).

```
void swapV(int x, int y) {       |  void swapR(ref int x, ref int y) {
  int tmp = x; x = y; y = tmp;   |    int tmp = x; x = y; y = tmp;
}                                |  }
                                 |
a = 11; b = 22;                  |  a = 11; b = 22;
swapV(a, b);                     |  swapR(ref a, ref b);
```



Reference parameters, continued

A reference parameter is declared using the `ref` or `out` modifier:

- A `ref` parameter is used for input and/or output.

  Using a `ref` parameter may avoid copying arguments at parameter passing.

- An `out` parameter is used for output only.

  Using an `out` parameter, a method may return multiple values.

  Example: Return true if removal succeeded and use `out` parameter to return the removed value:

  ```
  class TreeDictionary<K,V> {
    bool Remove(K key, out V val);
    ...
  }
  ```

  Example use:

  ```
  TreeDictionary<String, Person> students = ...;
  Person res;
  if (students.Remove("Ulrik Funder", out res))
    res.MailTo("You have been thrown out of university");
  else
    ShowMsg("Student not found");
  ```

The actual argument expression must have the same modifier (`ref`, `out` or none) as the formal parameter.

Properties (C# Precisely section 10.13, 12.16)

Fields are usually made private. Then `getP` and `setP` methods are often used to get and set fields.

In C#, such methods are called *properties*. They have method-like declarations and field-like call syntax.

Example: A last-in first-out stack of `doubles`:

```
class Lifo {
  private double[] stack = new double[10];      // Holds stack elements
  private int sp = -1;                          // Points to stack top
  public void Push(double x) { stack[++sp] = x; }
  public double Pop() { return stack[sp--]; }
  public int Count {                            // Read-only property
    get { return sp+1; }
  }
  public double Top {                           // Read-write property
    get { return stack[sp]; }
    set { stack[sp] = value; }
  }
}
```

Example use:

```
Lifo lifo = new Lifo();
lifo.Push(2.3); lifo.Push(5.4);
Console.WriteLine(lifo.Count);             // 2
Console.WriteLine(lifo.Top);               // 5.4
lifo.Top = 6.7;
```


Indexers (C# Precisely section 10.14, 12.17)

An indexer permits array-like method calls.

Example: Last-in first-out stack; indexing relative to the stack top:

```
class Lifo {
  private double[] stack = new double[10];      // Holds stack elements
  private int sp = -1;                          // Points to stack top
  ...
  public double this[int i] {                   // Read-write indexer
    get { return stack[sp-i]; }
    set { stack[sp-i] = value; }
  }
}
```

Example use:

```
Console.WriteLine(lifo[0]);
lifo[1] = 7.8;
```

The indexers of a class or struct are distinguished only by their signature (parameters).

Operator overloading (C# Precisely section 10.15)

As in C++, operators (+, *, <, ==, ...) can be overloaded.

An overloaded operator is a public static method. At least one argument must have the enclosing type.

Operators work well with value-oriented types, such as struct types; no risk of arguments being `null`.

Example: Arithmetic operators on fractions:

```
struct Frac : IComparable {
   public static Frac operator+(Frac r1, Frac r2) {
     return new Frac(r1.n*r2.d+r2.n*r1.d, r1.d*r2.d);
   }
   public static Frac operator*(Frac r1, Frac r2) {
     return new Frac(r1.n*r2.n, r1.d*r2.d);
   }
   public static Frac operator++(Frac r) {           // Pre- and post-increment
     return r + 1;
   }
   public static bool operator==(Frac r1, Frac r2) {
     return r1.n==r2.n && r1.d==r2.d;
   }
   public static bool operator!=(Frac r1, Frac r2) {
     return r1.n!=r2.n || r1.d!=r2.d;
   }
   ...
}
```


User-defined conversions (C# Precisely section 10.16)

A user-defined conversion is an operator named by the conversion's target type.

Conversions may be implicit (require no cast) or explicit (require a type cast).

Converting between integers, doubles and fractions is useful:

```
struct Frac : IComparable {
  public readonly long n, d;
  public Frac(long n, long d) { ... }
  public static implicit operator Frac(int n) { return new Frac(n, 1); }
  public static implicit operator Frac(long n) { return new Frac(n, 1); }
  public static explicit operator long(Frac r) { return r.n/r.d; }
  public static explicit operator float(Frac r) { return ((float)r.n)/r.d; }
  ...
}
```

Example of user-defined conversions:

```
Frac f1 = (byte)5;                          // Implicit int-->Frac
Frac f2 = 1234567890123L;                   // Implicit long-->Frac
int i1 = (int)f1;                           // Explicit Frac-->long
double d2 = (double)f2;                     // Explicit Frac-->float
```

An implicit conversion should lose no information and throw no exceptions; an explicit conversion may.

Delegates and delegate types (C# Precisely section 17)

A delegate encapsulates a (static or non-static) method. A delegate type is a method type.

Example: Declare `IntPredicate` as type of method that takes an `int` argument and returns a `bool` result:

```
delegate bool IntPredicate(int x);
```

Example: Methods `Even` and `PrintBig` has that type:

```
static bool Even(int x) { return x%2 == 0; }
static bool PrintBig(int x) { Console.WriteLine(x); return x > 100; }
```

Therefore method `Even` can be wrapped as an `IntPredicate` delegate object:

```
IntPredicate m = new IntPredicate(Even);
Console.WriteLine(m(4));                    // Prints: True
```

A delegate is multicast: it can encapsulate more than one method, and more than one instance of a method:

```
m += new IntPredicate(PrintBig);
m += new IntPredicate(PrintBig);
Console.WriteLine(m(7));                    // Prints: 7 7 False
```

In Java, there are no delegates; instead a method in an instance of an anonymous inner class may be used.

Enum types (C# Precisely section 16)

Unlike in Java, an enum value is really an integer, and enum types cannot have methods.

The integer value of an enum member can be given explicitly.

Example: Month codes 1–12:

```
public enum Month {
  Jan=1, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
}
```

Unlike in Java, enum values admit arithmetic operations such as `++`:

```
public static Date FromDaynumber(int n) {
  ...
  Month m = Month.Jan;
  int mdays;
  while ((mdays = MonthDays(y, m)) < d) {
    d -= mdays;
    m++;
  }
  return new Date(y, m, d);
}
```

Unlike in Java, computing with an enum type may produce an integer value not corresponding to an enum value.

The foreach statement (C# Precisely section 13.6.2)

Similar to Java's enhanced for statement.

Permits iteration over types that implement IEnumerable or IEnumerable<T>, including arrays.

Later we shall see how to easily write enumerable types.

Example: Truncating and summing the elements of an array:

```
double[] arr = { 9.213, 91.345, 410.0, 323.5, 930.25 };
int sum = 0;
foreach (int v in arr)
  sum += v;
```

The foreach loop is equivalent to a while-loop over an enumerator, followed by a call to Dispose:

```
IEnumerator enm = arr.GetEnumerator();
try {
  while (enm.MoveNext()) {
    int v = (int)(double)enm.Current;          // Explicit cast, not in Java
    sum += v;
  }
} finally {
  IDisposable disp = enm as System.IDisposable;
  if (disp != null) disp.Dispose();
}
```


The IDisposable interface (C# Precisely section 13.10)

```
interface IDisposable {
  void Dispose();
}
```

The Dispose method should release resources held by an enumerator or file or other object.

This permits early explicit resource deallocation, when there is no need to wait for the garbage collector.

The using statement (C# Precisely section 13.10)

C#'s using statement:

```
using (t x = e)
  body
```

is equivalent to:

```
{
  t x = e;
  try     { body }
  finally { if (x != null) ((IDisposable)x).Dispose(); }
}
```

Creation of some resource by x = e and its deallocation by x.Dispose() are textually linked.

A simple but useful idiom.

Variable-arity methods (C# Precisely section 10.7 and 12.15.3)

As in Java, the last parameter of a method may be a parameter array, thus permitting variable-arity methods.

The C# declaration syntax is (params t[] xs) where in Java is it (t... xs) .

Example: A Max method taking one or more arguments, and a Max method taking two:

```
static int Max(int x1, params int[] xr) {
  int res = x1;
  foreach (int x in xr)
    res = Max(res, x);
  return res;
}
static int Max(int x, int y) {
  return x > y ? x : y;
}
```

Overloading resolution prefers the explicit two-argument method over the one-or-more argument method.

Example uses:

```
Console.WriteLine(Max(69, 42));                           // Max(int,int)
Console.WriteLine(Max(2, 5, 7, 11, 3));                   // Max(int,int[])
Console.WriteLine(Max(2, new int[] { 5, 7, 11, 3 }));  // Max(int,int[])
```


Namespaces (C# Precisely section 25)

In Java:

- Types can be organized in *packages*, which have accessibility effect (default accessibility).
- The import declaration is used to access another package.
- The source file hierarchy reflects the package structure.

In C#, an analogous concept is the *namespace* and the using declaration.

But namespaces are not reflected in the source code structure.

And namespaces have no accessibility effect: the internal modifier concerns compilation units.

```
using System;
namespace N1 {
  public class C11 { N3.C31 c31; }           // N1 depends on N3
  namespace N2 {
    public class C121 { }
  }
}
class C1 { }                                // Default accessibility: internal
namespace N1 { public struct S13 { } }
namespace N1.N2 { internal class C122 { } }
namespace N3 { class C31 { N1.C11 c11; } }   // N3 depends on N1
```

String formatting (C# Precisely section 7.2)

C# has a rich and convenient machinery for formatting strings, numbers, dates and times.

Example: Assume `freq[c]` is the number of times rolling two dice gave `c` eyes.

Basic printing, using `{0}` to specify first value, and so on:

```
for (int c=2; c<=12; c++)
  Console.WriteLine("{0} came up {1} times", c, freq[c-1]);
```

Specifying formatting widths 2 and 4 using `{0,2}` and `{1,4}`:

```
for (int c=2; c<=12; c++)
  Console.WriteLine("{0,2} came up {1,4} times", c, freq[c-1]);
```

The two outputs:

```
2 came up 264 times                    2 came up  264 times
3 came up 572 times                    3 came up  572 times
4 came up 797 times                    4 came up  797 times
5 came up 1188 times                   5 came up 1188 times
6 came up 1426 times                   6 came up 1426 times
7 came up 1723 times                   7 came up 1723 times
8 came up 1353 times                   8 came up 1353 times
9 came up 1086 times                   9 came up 1086 times
10 came up 767 times                  10 came up  767 times
11 came up 558 times                  11 came up  558 times
12 came up 266 times                  12 came up  266 times
```


Command line compilation and execution of C# programs (C# Precisely section 1)

To edit C# programs, use Visual C# Express 2005, or any editor (Emacs, UltraEdit, Notepad, . . .).

C# programs can be compiled and run from Visual C# Express, or from a .Net Framework SDK Command Prompt.

To open a .Net Framework SDK Command Prompt, choose

```
Start
--> All Programs
--> Microsoft .Net Framework SDK v2.0
--> .Net Framework SDK Command Prompt
```

To compile a C# program in file `Foo.cs`, type

```
csc Foo.cs
```

This creates a file `Foo.exe` — looks like a classic x86 executable, but isn't. It requires .Net 2.0.

To execute the compiled program, type

```
Foo
```


Plain database access via ODBC (C# Precisely example 194)

Assume the server `sql.dina.kvl.dk` has a user `sestoft` with a database `test`.

We can connect to that database as follows:

```
String setup =
  "DRIVER={MySQL ODBC 3.51 Driver};"
  + "SERVER=sql.dina.kvl.dk;"
  + "DATABASE=test;"
  + "UID=sestoft;"
  + "PASSWORD=........;";
using (OdbcConnection conn = new OdbcConnection(setup)) {
  conn.Open();
  ... query the database (next slide) ...
}
```

Assume that database `test` has a table `Message`:

```
+--------+--------------+----------+
| name   | msg          | severity |
+--------+--------------+----------+
| Peter  | lunch        |       30 |
| Kasper | day off      |       10 |
| Dan    | coffee break |       20 |
+--------+--------------+----------+
```


Querying the database and reading result sets

Using the connection object `conn` previously obtained:

```
conn.Open();
String query = "SELECT name, msg, severity FROM Message ORDER BY name";
OdbcCommand cmd = new OdbcCommand(query, conn);
OdbcDataReader r = cmd.ExecuteReader();
while (r.Read()) {
  String name = r.GetString(0);
  String msg  = r.GetString(1);
  int severity = r.GetInt32(2);
  Console.WriteLine("{0}: {1} ({2})", name, msg, severity);
}
r.Close();
```

This is very similar to Java's JDBC-bindings.

There's a far more elaborate machinery in ADO.NET; see the classes in namespace System.Data.

The approach shown above is hard to maintain, and it is difficult to make sure that C# code and database agree.

In the future (around 2008) database access from .Net will have much better compile-time safety.

Namely, C# 3.0 and VB.NET 9 will have *Language Integrated Query* (Linq), see `http://msdn.microsoft.com/netframework/future/linq/`.